Available online at http://ejournals.uofk.edu

UofKEJ Vol.3 Issue 2 pp. 35-39 (August 2013)

UNIVERSITY OF KHARTOUM ENGINEERING JOURNAL (UOFKEJ)

Prediction of Swelling Pressure for Compacted Expansive Soils

Magdi M. E. Zumrawi

Department of Civil Engineering, Faculty of Engineering, University of Khartoum
Khartoum, Sudan (E-mail: magdi.zumrawi@yahoo.com)

Abstract: This study aims to predict swelling pressure in compacted clay from given soil index parameters such as dry density, water content, void ratio, clay content and plasticity index. Three different clay samples were prepared with varying water contents and dry densities. The swell-consolidation method was used to measure the swelling pressure, P_s. Analysis of the tests results demonstrates very clearly a strong linear relationship of P_s with the Factor of initial soil state, F_i, combination of water content, dry density and void ratio. The coefficients of this linear relationship (i.e. constant and slope) were found to depend on plasticity index and clay content. It is shown that predicted values of swelling pressure obtained from the proposed relationship agree closely with the experimental results of this study and those reported in the literature.

Keywords: *Pavement; Design guide; Expansive soils; Swelling.*

1. INTRODUCTION

The fine-grained soils containing expansive minerals undergo swelling upon ingress of water. The swelling of clays depends upon type of clay mineral (Amount of mineral montmorillonite), moisture content and surcharge weight[1]. The characteristic of expansiveness represented by swelling pressure is considered as a major parameter in design of engineering structures. Whenever swelling is restrained, swelling pressure develops.

Swelling pressure is defined here as the pressure required to compress the specimen, that has soaked and completed the swell under seating pressure, back into its original configuration (before swell). Many different methods have been developed for estimating the swelling pressure of soils; they can be broadly classified as “indirect methods,” which involve application of soil properties and classification such as dry density, water content, consistency index and activity, and “direct methods,” which provide actual physical measurement of swelling pressure, such as constant volume swell test and swell-consolidation method. Experiments by three methods to determine the swelling pressure of clays showed that the conventional consolidation test gives an upper bound value, the method of equilibrium void ratios for various consolidation pressures gives the least value, and tests by the constant volume method give intermediate values. However there is no definite relationship between the three methods[2].

The present study is based on empirical approach to predict the swelling pressure from the soil initial state parameters such as dry density, water content and void ratio as well as the soil index properties, plasticity index and clay content.

Attempts have been made by some investigators to correlate Swelling Pressure with various soil properties[3]-[6].Careful study of the proposed equations reveals that the investigators used for development of correlations some factors influencing the swelling pressure. These factors can be grouped into two broad categories, compositional and environmental factors. The compositional factors are known to reflect type and amount of clay minerals such asliquid limit, plasticity indexand activity. Whereas, initial watercontent, dry density and void ratio fallsunder environmental factors.

Komornik and David [3] carried out swelling pressure tests on natural (undisturbed) clay soils and developed the following relationship:

$$\log P_s = -2.132 + 0.0208 w_L + 0.00665 \gamma_d - 0.0269 w_i \qquad (1)$$

where, P_s: is the swelling pressure in kg/cm^2, w_L: is liquid limit, γ_d: is the initial dry density in kg/m^3, w_i: is the initial water content.

Nayak and Christensen [4] gave statistical relationship for swelling pressure as:

$$P_s = 2.5 \times 10^{-1})(PI)^{1.12} \times C^2 / w^2{}_i + 25 \qquad (2)$$

where, P_s: is the swelling pressure in KN/m^2, PI: is plasticity index, C: is the clay content, w_i: is the initial water content.

Rani and Rao[5]studied the influence of four types of clay of different liquid limit and plasticity index compacted at different moisture contents and dry densities on the swelling pressure.They suggested an equation to predict the swelling pressure (P_s) using the placement conditions factors such as moisture content(m_c), dry density (γ_d) and initial surcharge pressure (S_i) and compositional factors, liquid limit (w_L) and plasticity index (I_p) as :

$$LogP_s = a_0 + a_1(w_L) + a_2(I_P) + a_3(Log\gamma_d) + a_4(m_c) + a_5(S_i) \quad (3)$$

The values of a_0, a_1, a_2, a_3, $a_4$anda_5 were obtained from multiple regression analysis as -4.3341, 0.0071, 0.0006, 51.2802, 1.79 and 0.0037, respectively.

Erzin and Erol[6] carried out standard constant volume swell tests on a number of statically compacted samples of clay mixtures. They reported that the swelling pressure is strongly dependent on initial dry density (γ_d) and plasticity index (*PI*), but less affected by initial water content and developed the following relationship:

$$\log P_s = -5.020 + 0.01383PI + 2.356\gamma_d \quad (4)$$

2. MATERIAL AND METHODS

The primary objective of this paper is to predict the swelling pressure of expansive soils using soil initial state parameters such as water content, dry density and void ratio as well as soil index properties such as clay content and plasticity index. To achieve this objective an experimental testing program was conducted on soil samples collected from three different locations of expansive soils in Sudan. Soil samples were compacted with wide range of water content and dry density.

The Oedometer cell was used to measure the swelling pressure of the compacted soil samples. The samples were compacted at different initial water contents and dry densities. The soil was initially allowed to swell under a seating pressure of 1psi (≈ 6.9 KPa) and after reaching a peak swelling value, it was then compressed by adding weights. The weights were added each day to retain back the initial volume of the sample. The pressure that compressed the expanded sample to its initial volume was considered as the swelling pressure. Thirty four tests were performed for measuring the swelling pressure.

3. RESULTS AND DISCUSSION

The experimental results of the measured swelling pressure with the measured soil properties, initial water content, dry density, void ratio and their combination, initial state factor of the tested samples are given in Table 1. The index properties of the soils are presented in Table 2.

Table 1. The swelling pressure tests and analysis results of the soils used

Sample	***w*(%)**	ρ_d **, g/cm^3**	e	F_i	P_s KPa
A_1	20.38	1.588	0.70	11.1	113.5
A_2	20.38	1.549	0.74	10.2	77.2
A_3	20.38	1.495	0.81	9.1	50.9
A_4	20.38	1.483	0.82	8.9	41.0
A_5	20.64	1.73	0.56	14.9	228.7
A_6	22.73	1.65	0.64	11.4	121.5
A_7	22.86	1.734	0.56	13.6	215.0
A_8	22.87	1.727	0.56	13.4	191.3
A_9	23.16	1.64	0.65	11.0	100.4
A_{10}	23.28	1.655	0.63	11.3	107.8
A_{11}	23.86	1.627	0.66	10.3	68.1
A_{12}	23.95	1.642	0.64	10.6	88.9
A_{13}	23.95	1.621	0.67	10.2	52.5
B_1	24.0	1.653	0.68	10.1	226
B_2	24.2	1.600	0.74	9.0	195
B_3	24.4	1.625	0.71	9.4	208
B_4	25.2	1.607	0.73	8.7	200
B_5	30.0	1.447	0.92	5.2	70
B_6	30.1	1.457	0.91	5.3	65
B_7	31.1	1.434	0.94	4.9	58
B_8	31.6	1.452	0.91	5.0	38
B_9	32.0	1.398	0.99	4.4	35
B_{10}	34.2	1.384	1.01	4.0	35
B_{11}	34.4	1.362	1.04	3.8	28
C_1	8.52	2.017	0.32	73.1	136.7
C_2	9.79	1.964	0.36	55.8	111.2
C_3	9.86	1.963	0.36	55.3	84.5
C_4	10.14	1.917	0.39	48.1	63.7
C_5	12.1	1.924	0.39	41.0	17.6
C_6	12.25	1.916	0.39	39.7	23.6
C_7	12.82	1.978	0.35	44.1	40.3
C_8	13.8	1.875	0.42	32.0	18.5
C_9	14.16	1.868	0.43	30.7	16.2
C_{10}	15.26	1.887	0.41	29.8	8.3

Table 2. Summary results of the studied soils index properties

Soil	PI, (%)	C, (%)	G_s	F_0	M	R^2
A	33	40	2.70	7.99	34.58	0.965
B	50	45	2.78	3.28	34.14	0.986
C	20	13	2.67	28.57	3.17	0.918

The measured swelling pressure of the soils samples were observed to be influenced by the initial dry density, initial water content and initial void ratio as well as the clay content and plasticity index.

Regression analysis of the experimental data indicated that it is possible to combine the initial state parameters in a way reflecting the influence of each of them on the swelling pressure. Therefore a new concept has been developed; this is called the initial state factor. This factor of compacted soil was first developed by Mohamed [7] and then modified by Zumrawi [8]. The initial state factor, F_i is defined as a combination of the soil initial state parameters such as dry density, ρ_d, water content, w and void ratio, e and can be expressed as:

$$F_i = \frac{\rho_d}{\rho_\omega} \cdot \frac{1}{w \cdot e} \text{ with } e = \frac{G_s}{\rho_d} - 1 \qquad (5)$$

where F_i: the initial state factor; ρ_d: the initial dry density of soil; ρ_w: the density of water; w: the initial water content of soil; e: the initial void ratio of soil and G_s : the specific gravity of soil.

To investigate the relationship between the initial state factor, F_i and the swelling pressure, P_s the tests results obtained in this study were given in Table 1. The relationships of the analysed data are shown in Fig. 1. The plots in the figure and the values of the correlation coefficient, R^2 as listed in Table 2 have clearly shown a linear relationbetween the swelling pressure, P_s and the initial state factor, F_i for all the data analysed. The straight lines shown in the plots of Fig.4 can be expressed as:

$$P_s = M * (F_i - F_0) \qquad (6)$$

where: F_0 is the value of F_i at zero swelling pressure, M is the gradient of the straight line.

Fig. 2 shows the relationship of F_0 and M with clay content and plasticity index for the swelling pressure data, it can be seen that, increasing clay content and plasticity index increases M and decreases F_0 values. The equations of the best fit lines are expressed thus:

$$F_0 = 0.93*(PI*C)^{-0.95} \qquad (7)$$

$$M = 263*(PI*C)^{1.19} \qquad (8)$$

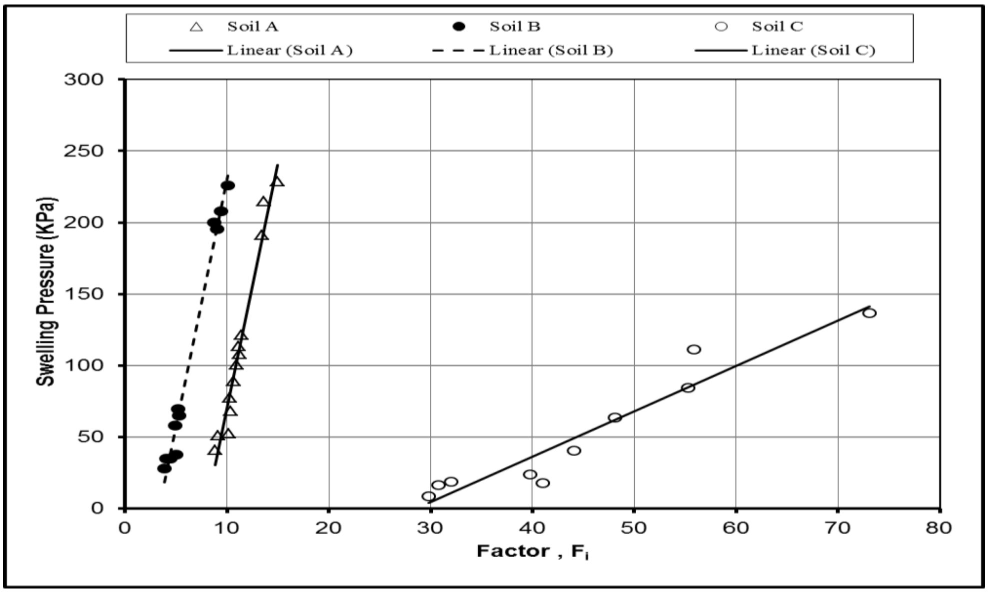

Fig.1. The linear relationship between the swelling pressure (Ps) and the initial state factor (F_i) for the studied soils samples.

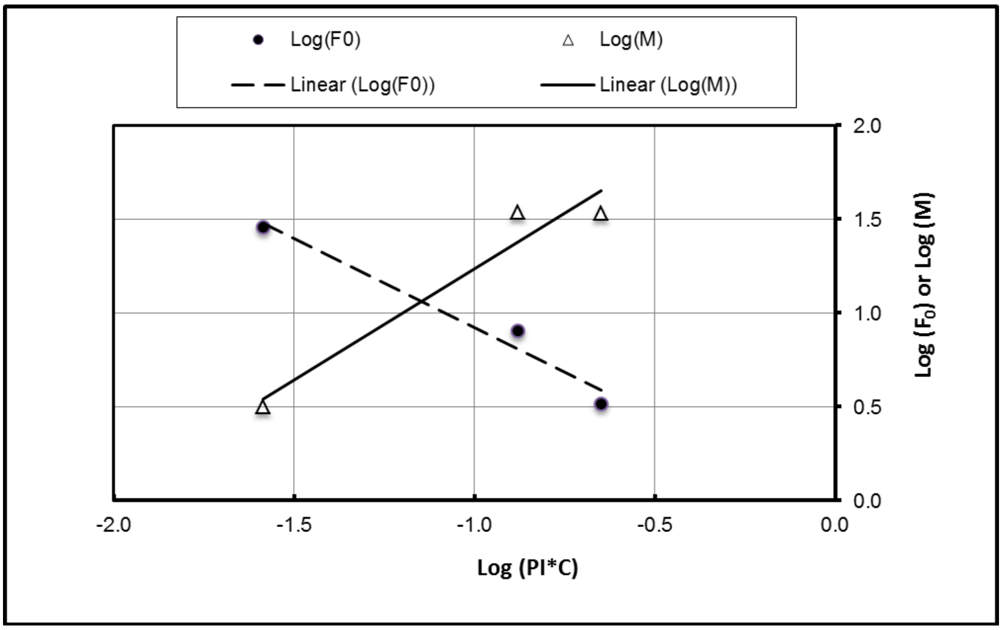

Fig. 2. Variation of F_0 and M with clay content, C, plasticity index and PI for the swelling pressure data

By substituting the values of F_0 and M as given in equations (7) and (8) into equation (6) and expressed swelling pressure, Ps as:

$$P_s = 263*(PI*C)^{1.19}\left[F_i - 0.93*(PI*C)^{-0.95}\right] \qquad (9)$$

where: F_i: is the initial state factor, PI : is the plasticity index, C : is the clay content.

Many investigators have conducted swellingpressure tests on compacted expansive soils reported in the literature. The previous empirical equations give reasonably good results when applied to the particular soils for which they were developed. Furthermore, they are easy to apply as they relate the swelling pressure to simple properties of soils which can be easily determined in any soil laboratory. Consequently, these equations are apparently lack the generality necessary to cover a broad range of soil types.

The validity of the proposed correlation for swelling pressure is assessed by comparing the predicted values of swelling pressure for the results of this investigation as well as using the data reported by previous investigators in the literature. Unfortunately, in most cases reported, the givendata are insufficient to apply the proposed equationto their soils,Nayak and Christensen [4]. However, comparison of the data reported by Rani and Rao[5]; Erzin and Erol[6]for thirty six soil samples is possible.The swelling pressure predicted by using the proposed equation 9 is plotted against measured swelling pressure for the results of this investigation and for the reported data. These plots are shown in Figs 3 and 4.The solid line in these plots indicates the line of equality. It is clear that many points are falling close to the line of equality. Some of the points are dispersed away from line of equality. This result indicates that there is a good agreement between the measured and predicted swelling pressure values and this has proved the validity of the developed equation.

4. CONCLUSIONS

Experimental work has been carried out to predict the swelling pressure of expansive soils from measured soil properties. Several tests to measure the swelling pressure and index properties were performed on samples compacted to a wide range of water content and dry density.

The initial state parameters of soil such as water content, dry density and void ratio were combined in a way reflecting the influence of each of them on swelling pressure. This combination was termed the initial state Factor, F_i. Analysis of the tests results clearly demonstrates a direct linear relationship existing between swelling pressure and the Factor, F_i.

Based on the linear relationship, a strong and reliable correlation has been established for swelling pressure with initial state factor, clay content and plasticity index.

Comparison of the measured and predicted swelling pressure values for all the data studied indicates that there is a good agreement between the measured and predicted swellingpressure values.

The swelling pressure and the soil properties seemed to exist in good relationship. This simple regression equation for prediction of swelling pressure is very useful.

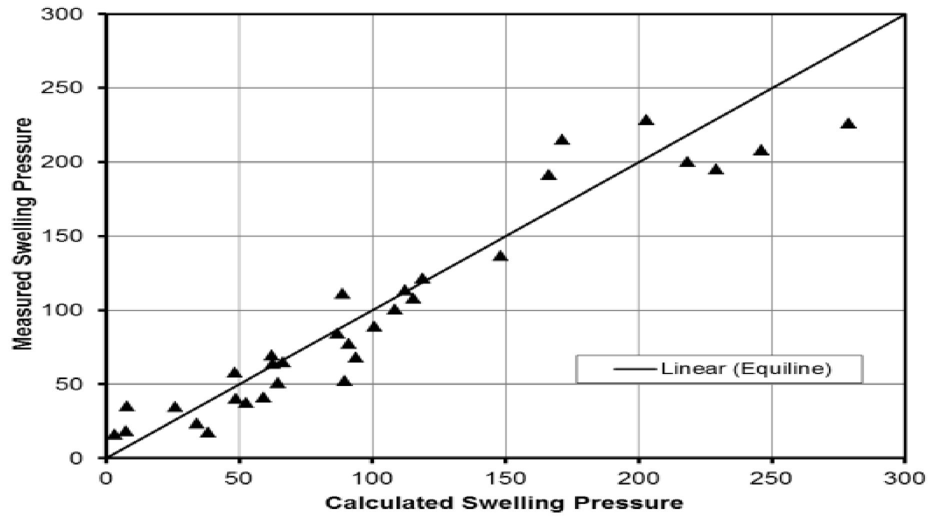

Fig. 3. Comparison of measured and predicted swelling pressure

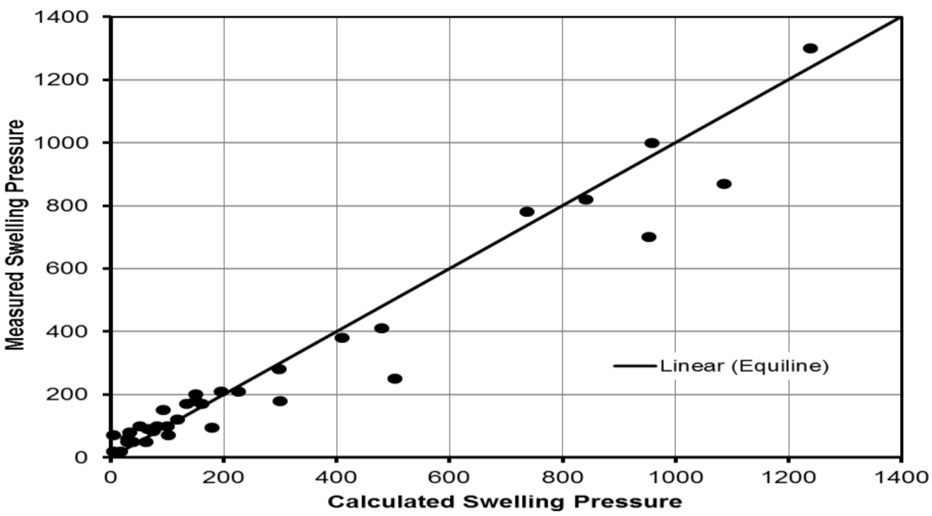

Fig. 4. Comparison of measured and predicted swelling pressure for the data reportedby previous investigators

REFERENCES

[1] Rao V.V (2013): "Swelling Pressure of Soil Predictive" Tool, International Journal of Computer Application (0975-8887), volume 63-No. -19.

[2] Sridharan A., Sreepada R. and Sivapullaiah P.V. (1986): "Swelling pressure of clays", Geotechnical Testing Journal, Vol. 9, No. 1, pp. 24-33.

[3] KomornikA. and David D (1969): "Prediction of swelling pressure of clays", Journal of SMFE Div., ASCE, Vol. 95, No. SM1, pp. 209-225.

[4] Nayak N.V and Christensen R.W (1974): "Swelling Characteristics of Compacted expansive Soils", Clays and Clay Minerals, Vol. 19, No. 4, pp. 251–261.

[5] Rani S. and Rao K.M. (2009): "Appropriate parameters for prediction of swelling pressure of expansive clays. IGC paper 2009, pp. 92 96. Guntur, India.

[6] Erzin Y. and Erol O. (2004): "Correlations for quick prediction of swell pressures". EJGE paper 2004-0476, Turkey.

[7] Mohamed A.E.M (1986): "Microstructure and swelling characteristics of an untreated and lime-treated compacted black cotton soil", Ph.D thesis. University of Strathclyde, UK, Glasgow.

[8] Zumrawi M.M.E (2000): "Performance and design of expansive soils as road subgrade", Ph.D. thesis, Chang'an Univ., China (2000).